PROBLEMS IN THE GEOLOGY OF NEW CALEDONIA.

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(With a note on the petrology of a small collection of schists, by
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(*Communicated by Professor L. A. Cotton.*)

(One Text-figure.)

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Introduction.

New Caledonia was so named by Captain Cook because of the resemblance of its east coast to the west coast of Scotland, rugged mountains and deep fiords lining the coast. New Caledonia is a country whose mountainsides are deeply indented with hollows, furrows, ravines and deep valleys.

Geological Constitution and Physiography.

The geological constitution of New Caledonia causes its physical features to possess a unique character. Excepting the north-eastern portion of the island, which is intensely metamorphosed, most of New Caledonia is composed of serpentine and Mesozoic sedimentary rocks, mingled with andesitic lavas and breccias of an easily decomposable nature.

The serpentines which form high mountains and ranges are largely untimbered, probably because of the high magnesia content of the soil, though the lower slopes composed of serpentine rubble are often covered with a dense scrub of wattle (a species of *Acacia* locally known as '*guiac*'), and of she-oak (a species of *Casuarina* locally termed '*bois de fer*').

The andesitic soils are lightly timbered with tea-tree (*Melaleuca* sp. locally known as '*niouli*') and this timber grows more thickly and is the dominant wood on the sedimentary formations. However, in the alluviated valleys in the niouli (tea-tree) country we often find dense scrubs similar to those of north Queensland rivers, in which many of the trees seem to be close allies of those occurring in Queensland scrubs. On the high plateaux in many parts there are scrubby valleys in which the kauri pine flourishes. Yet, generally speaking, the natural vegetation is extremely monotonous, especially as the settled parts of the island consist mostly of the fertile sedimentary and volcanic areas in which the forest is almost entirely one of paper-bark tea-tree (niouli). Of course today much of this country is variegated with introduced plants, amongst which guava, lantana, and sida-retusa figure largely.

It would seem that the whole island must have been inundated with lavas and submerged beneath the ocean in late Mesozoic times, so that all vestiges of early plant and animal life were destroyed, and later, upon re-emergence, it is probable that the seeds of hardy plant species have been carried on driftwood from Australia and from the Solomon Islands in the early Tertiary to initiate the present flora. The animal life supports the same supposition. There were no mammals, nor marsupials, in New Caledonia before the voyage of Captain Cook, and only one small reptile, a little lizard, the ancestors of which also might have arrived on pieces of driftwood.

Geological History.

The island of New Caledonia is a remnant of a once continuous continent, the Melanesian plateau, which extended westwards to Eastern Australia and New Guinea, and south perhaps to New Zealand. Its separation from these lands was not, like the destruction of Atlantis, an affair of the geological yesterday. It dates back to the Mesozoic period. Since then the whole island has been under the sea, has been inundated with lavas, partly submarine, partly terrestrial, has been overturned, folded, plicated and faulted by great convulsions and earth movements, and re-elevated by forces which had their origin in titanic pressures emanating from the ocean depths to the east.

It seems most reasonable to suppose that the hinge line dividing the essentially oceanic Pacific trough from the submerged, collapsed and foundered Australia–Melanesian plateau passed, in early Mesozoic times, along the great volcanic line, which runs through New Zealand, White Island, Tonga, the New Hebrides and Solomons to New Guinea. New Caledonia was the scene of marine transgressions in the Mesozoic, during which Triassic and Cretaceous sedimentary rocks were laid down, with interludes of land conditions during which the coal beds were formed. The siliceous sandstones and aluminous shales of these periods must have been derived from continental rocks such as granite, or sedimentary rocks derived from granite. They were laid down in shallow water under oscillating conditions, as shown by coal-beds in them. The limestones of these periods are also of such a nature as to suggest shallow-water conditions. The contemporary lavas, tuffs, breccias and agglomerates are mostly andesitic, therefore neither truly oceanic nor truly continental; occasionally thin sheets and dykes of trachyte occur in them.

Fossils are not usually abundant, but do occur in abundance in a few places. Even then they are usually very crushed as a result of earth-movements and are not often identifiable as regards species. Yet the early French geologists, Garnier, Heurteau and Pelatan, succeeded in identifying a fair number and definitely found several species identical with those of the Triassic and Cretaceous of New Zealand. Indeed, New Zealand, both in its sedimentary and volcanic sequence, is much akin to New Caledonia, but New Caledonia has undergone the more intense subsequent earth-movements.

The Mesozoic sediments of New Caledonia have all been strongly folded. In the southern half of the island it is easily seen that the folding becomes rapidly more intense as we proceed from west to east towards the edge of the serpentine, near which overfolding and plication are common. The serpentine intrusions were apparently the cause of the pressure and thrust movements producing the folding, as well as of a considerable amount of faulting, crush and shearing.

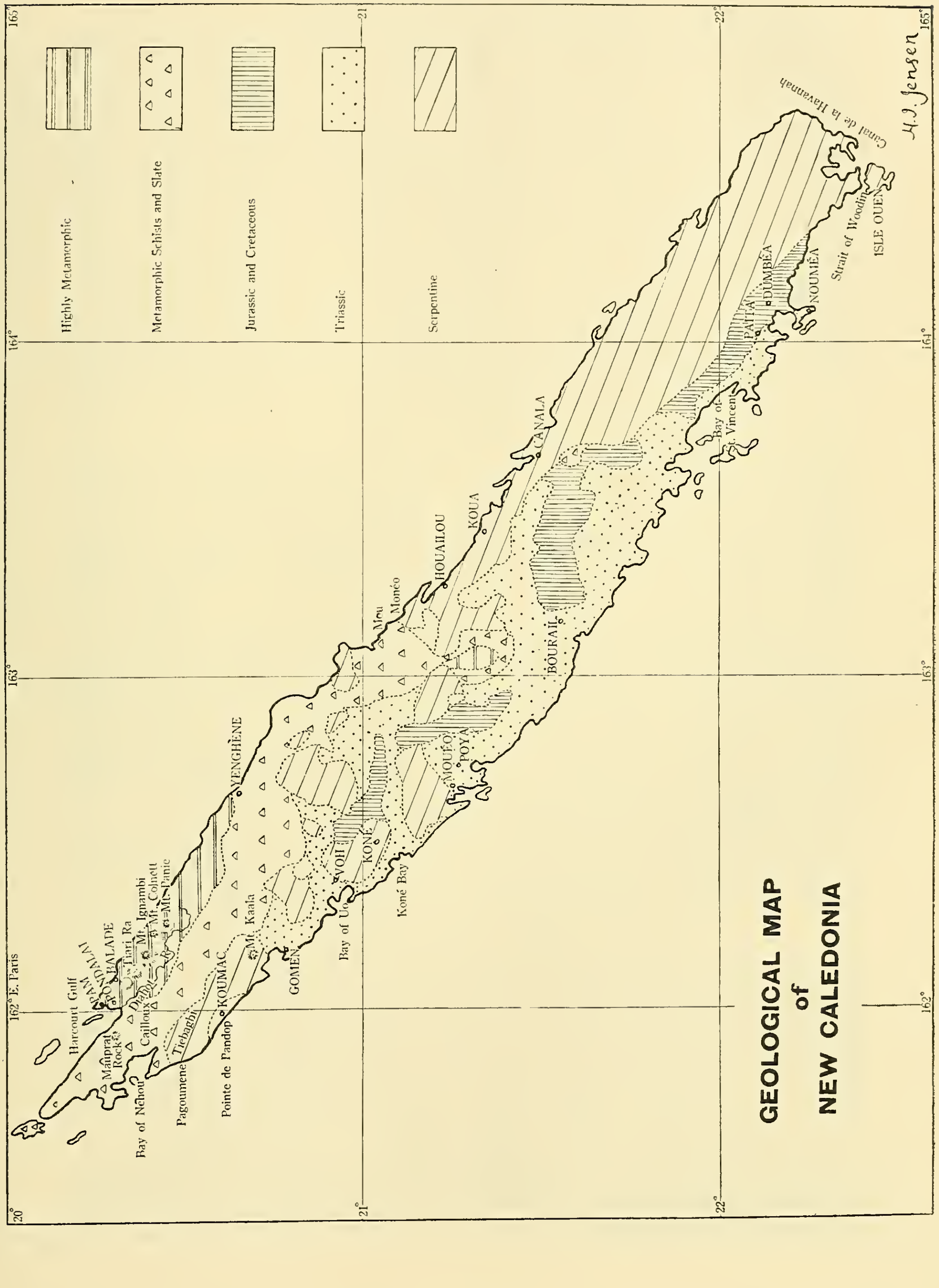
The dip seldom remains constant in direction or angle for any great distance. For example, Noumea is built on andesitic lavas, tuffs, breccias and sedimentary rocks of Jurassic–Cretaceous age. The southern suburbs are partly on sandstone and limestone moderately folded. East of the town there are high hills composed of volcanic tuffs, breccias, agglomerates and conglomerate, the latter containing a mixture of andesite, sandstone, limestone, chert and shales. The volcanic tuffs and breccias near the north end of the town about the railway station dip to the south-south-west at a regular angle of about 30°. The same series under the Catholic Cathedral at the south end of the town dips north-east at steep angles—from 45° to 70°—and the beds are frequently plicated and contorted by crush. The breccias and tuffs east of the town change frequently in dip, the road-cuttings showing numerous minor folds. The most regular bedding that I have noticed in New Caledonia was in the Bourail district, where the Mesozoic rocks dip eastwards near the west coast, then change to westerly dip which prevails to a few kilometres east of Bourail, when the dip again becomes easterly and subject to plications as the serpentine is approached.

Near Paita the Mesozoic sedimentaries are steeply inclined, vertical in places, in others overfolded. Again, near Dumbéa, calcareous shales, limestones and coal-beds of Cretaceous age have been intensely crushed and are standing almost vertically in places. Yet, generally speaking, the sedimentary rocks occurring west of the serpentines are not metamorphosed. On the other hand, the sedimentary rocks occurring east of the serpentine belt in the north part of the island are not only steeply folded and plicated, but are intensely metamorphosed as well, sandstones being changed to quartzite and sandy schist, shales to aluminous schist and limestone to crystalline limestone. Yet in this schist series east of Koumac Cretaceous fossils have been obtained. Thus the highly schistose series developed east of the serpentine belt is, at least in part, coeval with the less altered sedimentaries.

The Metamorphics.

The metamorphic rocks east of Koumac just referred to are, as far as the Diahot River, schistose but not highly crystalline, though in a few places on the Divide they grade locally into mica-schist with glaucophane-schist. Judging by the composition of the schistose rocks east of the Diahot, the composition of the soils on them and by the vegetation, quite apart from the paucity of fossil evidence, I consider this series altered Mesozoics. The Diahot River divided this series from a block of high mountain country, with peaks more than 5,000 feet high, consisting of intensely crystalline, and coarsely crystalline metamorphic rocks which comprise ordinary mica-schist, micaceous phyllite, coarsely crystalline quartzite, garnetiferous quartzite, amphibolite and glaucophane schist, and a vast proportion of schists which contain variable proportions of muscovite, glaucophane, other amphiboles and garnet. These glaucophane schists are probably all derived from volcanic lavas and tuffs, and from semi-tuffy sedimentary rocks. Since the schistose series west of the Diahot valley passes in places into crystalline schists of the same type as those east of the Diahot, it is my opinion that the great crystalline schist series of north-eastern New Caledonia is derived from the same kind of Mesozoic sedimentaries with interstratified tuffs, breccias and melaphyres as extend in the unmetamorphosed form through the western part of the island.

Several of the French geologists have regarded the crystalline schists of the north-east as a very old formation comparable with the Ordovician of Victoria. I am, however, inclined to regard them as the same Mesozoic agglomeration of strata as in the west of the island, which has been completely fused up and recrystallized by having been lowered or foundered into the zone of fusion. It has been subsequently re-elevated by the thrusts accompanying and following the extrusion of the serpentines. In many places in the crystalline schist area east of the Diahot we get semi-serpentinized rocks and amphibolites, parts of which are but little altered and which bear the closest resemblance to the vesicular andesite and melaphyre in other parts of the island.


GEOLOGICAL MAP
of
NEW CALEDONIA
Highly Metamorphic
Metamorphic Schists and Slate
Jurassic and Cretaceous
Triassic
Serpentine
H. I. Jensen
Canal de la Havannah
ISLE OUEN
Strait of Woodin
NOUMÉA
DUMBÉA
PAÏTA
Bay of St. Vincent
CANALA
KOUA
HOUAILOU
BOURAIL
Monéo
Meu
POYA
MOUÉO
KONE
VOH
Koné Bay
Bay of Uo
GOMEN
VENGHÈNE
Mt. Kaala
KOUMAC
Pointe de Pandop
Pagoumene
Tiebaghi
Bay of Néhoué
Caillou
Maupral Rocks
Harcourt Gulf
PAM
BALADE
Tiari Ra
Mt. Ignambi
Mt. Colnett
Mt. Panie
162° E. Paris
163°
164°
165°
20°
21°
22°

Earth Processes and the Serpentines.

To understand fully the processes which have taken place it is necessary to comprehend the distribution of the serpentines in New Caledonia. The entire southern end of the island is serpentine. On the west coast the Mesozoic sedimentaries commence to show half-way between the south end of the island and Noumea, attaining its maximum width in the vicinity of Bourrail, and the main serpentine axis hugs the east coast northwards as far as Houailou (Wailou). Here the serpentines leave the east coast and the axis passes to the centre of the island as far as Poya and then the serpentine belt swings over to the west coast. From Mouéo north the serpentines largely squeeze out the sedimentary series, of which pockets are left at Voh, Gomen and Koumac, but the serpentine has become the dominant west-coast formation. The serpentine belt is very continuous to Koumac, then is lost for a score of kilometres, apparently covered by Tertiary sedimentary formations, but resumes in the dome of Tiebaghi north of Koumac. As mentioned before, west of the serpentine belt the sedimentaries are folded and even contorted near the serpentine, but not metamorphosed, while east of the serpentine belt they are metamorphosed. West of the serpentine belt all the limestones are ordinary limestone, east of it they are crystalline limestone.

The more highly metamorphosed nature of the rocks east of the serpentine is easily explained on the supposition that the basic lavas now altered to serpentine (originally peridotite and dunite), were thrust up from the oceanic depths east of New Caledonia between that island and Tonga, and advanced as a sill under the Mesozoic sedimentaries for a considerable distance before breaking through. The roof rocks of the intrusion were therefore subjected to much more metamorphism and plication than the rocks underlying the intrusion, the heat of the intrusion causing expansion of strata, shearing movements, and schistosity.

This, while explaining the greater schistosity of the rocks east of the serpentine belt, does not explain the greater metamorphism of the titanic block east of the Diahot which is further from the serpentine belt. But if we imagine a portion of the roof rocks to have subsided into the zone of fusion, into a cauldron, so to speak, of molten peridotite magma, it is easy to understand its complete metamorphism. A further movement of the still plastic peridotite magma has subsequently pushed this intensely altered block up again so that it now over-rides the serpentines and the less altered metamorphics.

The crystalline schists form the highest country in New Caledonia. Mt. Ignambi, Mt. Colnett and Mt. Panie exceed 5,000 feet in height. There are dykes and masses of serpentine included in the crystalline complex.

In the country immediately near the Diahot several shear zones strike NNW. and NW., consisting largely of quartz and chlorite, and dipping steeply to the east. These quartz-chlorite zones have developed in the crush material of the movement planes of the last big thrusts. The intensely metamorphosed crystalline schist block rides on these great shear zones, and is portion of the super-serpentine roof rock which has been engulfed in the zone of fusion, pushed up again by further thrusts from the east. Great movement planes and master joints in the crystalline series dipping east indicate a dragging differential movement. Thrusts from the south also took place, developing another set of master joints with movement on them dipping south-east. In some places there have been pressure movements causing gliding planes in so many directions that we get schists weathering out into masses like logs of wood each 5 to 6 feet long and about 2 feet in diameter. That may be well seen on the Balade Road about half a mile from the Cailloux.

It is seldom possible to determine the original dip of the crystalline schist masses. The dips within them are cleavages parallel to movement and thrust planes and at right angles to cooling planes. They are in fact controlled by the major joint directions.

A belt extending from Pondalai to Fern Hill shows a general south-westerly dip at gentle to moderate angles west of the Cailloux–Pam road, but within the belt there are several reversals and contortions. This belt lies west of the great quartz-chlorite shear-zones. The rocks within it are not as highly crystalline as those east of it. There are many quartz reefs in it running mostly north and south. In the Tiari and Reussites range, east of the main quartz-chlorite shear, the dip changes to easterly and the same east to south-east dip at steep angles is maintained east of the road to Pam. But it is far from constant, for at the Balade Mine the dip is again south-westerly. On and along the east coast the dip is generally easterly, with numerous deviations, but in the whole of the mass between the Diahot River and the east coast there are thrust-planes and strong joints developed by crush and movement, the latter shown by alteration to chlorite and deposition of quartz, dipping south-east in the south-eastern part of the massif, easterly in the central part and north-east in the northern part. The effect of these thrust-planes is to produce long regular slopes on the east coast, where the thrust-planes and dip usually agree, and a rough serrated configuration in the western part of the massif.

The rocks of the massif comprise mica-schist, sericite-schist, talc-schist, quartzite, garnetiferous quartzite, garnet-rock, amphibolite, serpentine, glaucophanite, tremolite, and a variety of gneissic mixtures grading from one of these to the others.

The country west of the Diahot right to Koumac is metamorphic, but not so strongly. It is, however, folded to such an extent that for a distance of eight kilometres across the central range, at right angles to the strike, the beds stand vertical or nearly so. On the east side of the central point, the Crescent, there is a tendency to an easterly dip and on the west side to a westerly dip. The country, therefore, suggests a strongly compressed anticline, in each limb of which the same big body of crystalline limestone is represented. The other rocks are clay-schist, slate, sericite-schist, arenaceous schist, interbedded andesite, andesitic tuff and breccia, all traversed by quartz veins and reefs. There is minor folding between this anticline and the Tiari-Panie massif which probably sits on the geosyncline or partly on the geosyncline and partly on the eastern flank of a smaller anticline which occupies the line of the Diahot and Mauprat Rock, in which rock and adjacent hills the limestone belt is again repeated.

Age of the Serpentine.

The age of the serpentines is post-Mesozoic and earlier than Pliocene. The upper Tertiary (probably Pliocene) rocks west of Koumac overlie the serpentines, and conglomeratic beds in them contain pebbles of serpentine and jasper; the Miocene in the south of the island also overlie serpentine. Hence we may regard the serpentine (peridotite dunite) intrusions as Eocene and the grand upheaval of the Tiari–Panie crystalline complex as later, perhaps Miocene.

Comparison of Northern New Caledonia with North Queensland.

The high coastal range of Bellenden Ker and Bartle Frere south of Cairns, continued north of Cairns as the Dividing Range with Mt. Spurgeon and Mt. Windsor, attaining a general height of from 3,000 to over 5,000 feet, and also the high coastal and Dividing ranges north of Princess Charlotte Bay give a physiographic resemblance between these parts of the Queensland coast and the crystalline Panie mass of north-eastern New Caledonia. It has been suggested by Dr. H. C. Richards that possibly the 2,000-fathom Carpenter Deep has controlled the history of the Barrier Reef and possibly the thrusts which have caused movements along the North Queensland Coast (*Trans. Roy. Geog. Soc. Q.*, Vol. 1, n.s.). I have also suggested that the great movements of thrust in New Caledonia had their origin in the enormous deeps to the east of that island.

Here, however, the comparison ends. The great metamorphic-cum-igneous massifs of North Queensland consist of metamorphic rocks with granite intrusions, a 'continental' intrusive magma, while those of northern New Caledonia consist of metamorphics with ultrabasic, that is 'oceanic', intrusives.

The great shear zones and master-joint zones and the dip of the metamorphics in North Queensland are all steeply to the west, while the shears and master-joints and related dip-planes in the Panie massif are all to the east; in the former case the shears dip away from the deep ocean, in the latter towards it. In the North Queensland areas mentioned, the great igneous injections came up from the west and south-west; in the New Caledonian area they came up from the east and south-east.

Hence in the parts of North Queensland mentioned the shears, intrusions, folds, joints and dips were controlled by the wide and deep sedimentation of a subsiding continental mass to the west, whereupon granitic crustal magmas were driven away laterally from the parts most heavily sedimented into the rim of the sedimented area. A wide continental expanse existed east of the present coast which has since foundered. The basic and ultrabasic magmas played only a slight rôle in the process.

In the case of New Caledonia a continent lay to the west, most of which is now foundered. To the east were enormous oceanic deeps at the time of the igneous intrusions. An enormous line of weakness, the great volcanic zone of the Pacific, lay only a short distance to the east. Subsidence and engulfment of sedimentary strata in this zone and subsequent uplift connected with extrusions of magma from the deeps played a large part in the building of New Caledonia.

Comparison with the American Cordillera.

In the American Cordillera we have a coastal range, a central range and the Rocky Mountains. Both the Coastal Range on the west and the Rockies in the east are ge-anticlinal in structure and the formations involved range from Pre-Cambrian to Carboniferous and Mesozoic. The Central Range consists entirely of crystalline schists and granite and is geosynclinal in structure. The eminent French geologist Termier considered the crystalline schists produced by the fusion of folded Carboniferous and Mesozoic rocks in the geosyncline.

The glaucophane-schist series in the Dinaric Alps in Europe are also considered to be derivatives of Mesozoic rocks highly metamorphosed.

There is quite as much reason to consider the New Caledonian crystalline schists to be derived from the Mesozoic sediments by analogous extreme metamorphism.

Evidence of the Ore Deposits on Genetic Relationship between the Sedimentary and Metamorphic Rocks.

In the more volcanic portions of the folded and unmetamorphosed sedimentaries we have many shear zones developed in which the minerals of copper, silver, lead and zinc, often with a little gold, have been precipitated, in my opinion, by lateral secretion. The source of these minerals is metal contained in the hornblende of andesite and andesitic tuff, and hot springs have, at least in some cases, played a part in dissolving it out of the mother rock and precipitating it in shears, as shown by the frequent association of chalcedonic quartz with the lodes.

In the great crystalline schist block east of the Diahot we have the same metals contained in fissure lodes. A system of fissures in two directions at right angles striking 40° and 130° occurs and in them we get copper and silver-lead ore and more or less gold. Neither quartz nor any other mineral suggesting derivation from granitic or dioritic magma is present. The gangue is crush-rock, fault-breccia, kaolin and iron gossan. These lodes, too, owe, in my opinion, the ore content to lateral secretion. The copper of the Balade and Pam Mines, the silver-lead of the Meretrice, the gold of the Fernhill and Reussites, are probably all of this origin and derived from the highly metamorphosed volcanics now represented by glaucophane schist and amphibolite.

Acidic Rocks.

Granite occurs only in two places in New Caledonia, and there only over a small area, namely, at the source of the creeks of Saint Louis and Coulée where it is surrounded by serpentine, and a little more to the north-west in the cirque of Grosses–Gouttes. In both cases it is probable that the granite represents upthrusts of the broken edge of the old continental mass forced up by the serpentine along the great fracture zones which it followed.

Felsitic and trachytic rocks, however, occur as thin sheets and dykes in the mesozoic andesites, and it is interesting to record that similar rocks, but somewhat metamorphosed, are seen among the more basic members of the crystalline schists.

Description of the Coast and Coastal Movements of Recent Times.

The whole of the south end of New Caledonia is composed of serpentine, and the configuration of the coast in this part is indicative of rapid depression. Where subsidence is more rapid than silting up of harbours the deeper inlets are met. We get 30 to 40 metres of water in the strait of Woodin between the mainland and the island of Ouen which is a detached mountain of the mainland that has become separated by rapid subsidence. Further east in the Canal de la Havannah depths of 40 to 60 metres prevail. Along the whole east coast between the coral reef and the mainland as far north as Yenghène the depth of the water ranges from 40 to 70 metres. In the beautiful harbour of Canala, a sunken river valley, depths are 25 to 40 metres. Between the inner fringing reef and the outer barrier reef north of Houailou (or Wailou) and thence to Hienghen (Yenghène) we have depths of from 40 to 70 metres. The harbour of Koua, between Canala and Houailou, opening into a beautiful coastal lake (another sunken river valley), has depths of from 20 to 40 metres. Serpentine coastline with rugged mountains, bare or clad only with a growth of heaths, prevails from the extreme south to Moneo and Mu.

At Mu, about the middle of the east coast, schists commence to show, much harder and more metamorphosed than those on the west coast. The serpentines take a swing from the east coast to the middle of the island, opposite Poya, and thence swing over to the west coast at Mouéo, and then they occupy the west side of the island to Gomen forming high mountain ranges. A detached serpentine mass lies between Gomen and Koumac, in which there are several nickel mines; another, the Dome of Tiebaghi, lies north of Koumac, and in it occurs the famous chrome mine of Pagumene, a huge pipe of wonderful chrome-ore.

Returning to the east coast we observe, north of Moneo, hills and ranges clad with tea-tree (niouli) skirting the coastline, and in the higher ranges, about 5 miles back, escarpments of crystalline limestone can be seen. Common among the metamorphic rocks along the coast are the epidiorites and garnetiferous greywacke, weathering in huge black boulders, similar to those seen in the metamorphics east of the Diahot River. Coastal plain is negligible. The limestone belt approaches the coast closer and closer until it goes into the sea at Hienghen (Yenghène) and thence northwards it is under the sea.

The east coast north of Yenghène becomes more and more elevated as the Panie plateau of crystalline rocks develops, the mountains dropping sheer into the sea. The waters inside the Barrier Reef become shallower, namely from 20 to 30 metres, the silting up process towards the north keeping pace with depression. Th large river Ouaieme, south of the Panie massif, is not navigable and has only 6 to 8 metres of water at its mouth, as compared with 40 metres in the Canala entrance. The alluvial 'pointes' or peninsulas at Puebo and Balade, clad with mangroves, indicate, as does also the inter-reef channel, that as we go north silting up is overtaking subsidence. The large Harcourt Gulf, into which the Diahot enters, is only 10 to 12 metres deep in the channel, and the rest of it is largely sand-banks at low tide. The islands north of New Caledonia, like those to the south, are detached from the mainland by a great late Tertiary subsidence, which at its conclusion had made all the now alluviated Diahot Valley an arm or gulf of the sea, but, as subsidence slackened off, this arm was silted up again. That fact is evidenced by a number of bores which I supervised in the Diahot basin passing from river alluvial into coastal deposits, shell beds with *Arca*, *Potamides*, and an enormous variety of other shallow-water mudbank species.

The northern portion of the west coast was also subjected to rapid subsidence during the same part of the late Tertiary, but the movement has ended here, for the harbours of the west coast, the bays of Banare, Néhoue, Gomen, Koné, Uo, Voh, Bourail and St. Vincent, right to near Noumea, are all shallow, due to sedimentation from the decomposable serpentinous and Mesozoic strata behind exceeding any present depression. In places, I am informed, there are even small raised beaches, indicative of local elevation. South of Noumea, however, the west coast is rapidly subsiding.

Late Tertiary Elevation.

In spite of the general late Tertiary subsidence following upon the great post-serpentine uplifts, there are localities on the west coast where local Miocene and Pliocene elevations have taken place. Miocene rocks have been recorded from various places in southern New Caledonia, but these may have been contemporary with a local delayed spasm in the great early Tertiary uplift. However, west of Koumac, we get a fair area of uplifted Pliocene sediments which rise to form a group of small hills known as the Pointe de Koumac, or Pointe de Pandop. They consist of interlaminated mudstones, marls, sandstones, pebbly beds, peats and magnesian streaks, dipping west at an angle of 15° to 20°. They overlie serpentine.

A large serpentine massif, Mt. Kaala, lies south-east of the Pointe de Koumac and at its western base there is a remarkable oil seep coming out of a magnesian vein in the serpentine. An old man has been prospecting for oil here for a generation by sinking shafts and driving tunnels in the serpentine in a most patient manner. On some of his wells a scum of oil forms, which, by skimming, yields about a pint a day.

This oil can hardly be derived from the igneous serpentine, nor can it be derived from the metamorphic Cretaceous rocks which form the base and the eastern margin of the serpentine mass of Mt. Kaala. The metamorphic Cretaceous is schistose and the beds stand almost vertically. The most feasible explanation is that the oil is derived from the late Tertiary (Pliocene) beds to the west under the ocean and is being forced by water pressure into magnesian crevices in the serpentine whence it again escapes to the surface. The oil has the consistency of light machine oil and is of a brownish-green fluorescence. The oil-producing series probably extends a long way under the ocean to Chesterfield Island.

Summary of Movements.

The processes that went towards the building up of the present New Caledonia are therefore as follows:

(*a*). Oscillatory movements with heavy deposition of sandstone, shale, coal, marl, mudstone, limestone, tuff, breccia, agglomerate and conglomerate, and interbedded andesitic lavas on the eastern platform of the Melanesian continent during the Triassic, Jurassic and Cretaceous periods.

(*b*). Faulting with thrusts from the ocean deeps to the east, followed by an uprising of peridotite magmas in the late Cretaceous or Eocene, accompanied by, or followed by, further thrust movements from the east resulting in the upheaval of the New Caledonian platform and the folding of the Mesozoics. These movements may have extended in places into the Miocene.

(*c*). Deposition of Middle Tertiary beds on both sides of the platform. The overthrust of the crystalline schists in the north-east may have been as late as early Miocene. Local uplifts in the Koumac region, probably of earthquake nature, at the end of the Pliocene.

(*d*). Pleistocene subsidence on a grand scale leading to the separation of the Loyalty Islands and all the islands north and south of New Caledonia, this downward movement continuing to the present time in the south, and along the east coast from the south end to Hienghen, but arrested in Recent times in the north of the island and the northern half of the west coast.

(*e*). Cessation of depression and sedimentation by river deposition in the Diahot valley.

Literature on the Geology of New Caledonia.

The earliest geologists investigating this country, Jules Garnier and Heurteau, investigated principally the mineral resources of the island. M. Pelatan, in 1892 and the ensuing years, continued that good work. In 1901, M. Maurice Piroutet carried on stratigraphical and palaeontological investigations which added much to our knowledge. The researches of M. N. E. Glasser, in 1902 and 1903, carried the work of all these investigators still further, and his report (Annales des Mines, 2^{me} semestre, 1903; and 1er semestre, 1904) contains an excellent summary of his own, as well as all previous work.

In my own investigations I have neither had the time nor the opportunity to investigate palaeontological problems, but I may remark that, in country which has been subjected to such catastrophic vicissitudes as New Caledonia, one must expect much inter-mixture of fossils of various ages and confusion. It is almost certain that small remnants with Miocene and Eocene fossils will from time to time, as work proceeds, be found among the Mesozoic beds, lodged in unexpected positions by early Tertiary overthrusts and uplifts.

The Serpentine.—The French geologists have done a vast amount of excellent work on the chemical composition of the serpentines, instigated by the importance of these rocks in regard to ore deposits of nickel, chrome, cobalt, and manganese. Those interested in ores of these metals should study the work of Garnier, Heurteau and Glasser. It appears certain that the serpentine is derived from peridotite which was intruded before the elevation of the New Caledonian platform above sea-level. Ingress of sea-water in the course of the upheavals has probably contributed largely to the alteration to serpentine.

Ocean Soundings and their Bearing on Past Continental Areas.

Ocean soundings show waters ranging principally between 1,500 and 2,000 fathoms between Australia, the New Hebrides and New Caledonia, the Loyalty Islands and New Zealand. A marked shallow belt or range extends from Sandy Cape north-east to Wreck Reef, then to Chesterfield Reef, then to the north of New Caledonia, where soundings show less than 1,000 fathoms and mostly less than 500 fathoms. This sunken range is probably genetically related to the nearly east-west fundamental structural direction in the older Palaeozoic formations of the Australasian continental mass. This was probably also the last chain joining Australia to New Caledonia. The Admiralty chart shows no strong evidence of folding within the large area embraced between the coasts of New Guinea, Australia and New Caledonia over the Coral Sea. It looks like a subsided peneplained continental mass with isolated hills and ranges, and plains of sedimentation well submerged.

But from Sandy Cape south along the Australian coast commences a deep zone, exceeding 2,000 fathoms, and for the most part approaching 3,000 fathoms, which divided the platform of Lord Howe Island from the continent. The Lord Howe platform with depths ranging from 400 fathoms to 1,000 fathoms extends north-east to within 100 miles of New Caledonia, where the ocean deepens though it does not exceed 2,000 fathoms. The ocean chart, therefore, shows a strong synclinal or downfaulted block east of south-eastern Australia running in the same direction as the Australian coast and a less depressed, extended, but older, continental area, round Lord Howe Island, which extends right to Northern New Zealand, but which is separated from New Caledonia by a depression to 2,000 fathoms, which is of recent and late Tertiary development. The Loyalty Islands are separated from New Caledonia by water 1,000 fathoms deep, in places dropping to 2,000 fathoms. The irregularity of the bottom in this basin is evidence of continental depression, and the coral islands of the Loyalties are obviously built on sunken portions of the New Caledonian platform which, as already shown, is still sinking in the direction of the Loyalties.

But east of the Loyalty Islands we meet with a startling depression between these islands and the New Hebrides, deeps of 3,000 and 4,000 fathoms indicating a deep synclinal trough which has a NNW.–SSE. trend, less marked in both directions, though traceable northerly past the south of the Solomons and along that group on the western side and through the strait between the Solomons and New Ireland. Towards the south-east it occurs between New Caledonia and Tonga in ocean depths of between 2,000 and 3,000 fathoms. East of the line joining Kermadecs, Tonga, and Samoa, enormous depths exceeding 3,000 fathoms prevail.

Thus from the soundings it would appear that in times as remote as the Trias there was a continent extending over the Coral Sea, and also over the vast area between the Australian coast and New Zealand and New Caledonia (the Lord Howe Island continent). The present volcanic chain through Samoa and Tonga, the Kermadecs and New Zealand represented its eastern fringe. The Triassic rocks of New Zealand, New Caledonia, and Eastern Australia were deposited over lacustrine areas and marine transgressions over the continental shelf.

More transgressions followed in Jurassic and Cretaceous times, but in the upper Mesozoic periods the foundering of the Lord Howe Island continent had already commenced and had split it into groups of islands while waves of thrust from the subsidence areas caused the Cretaceous and post-Cretaceous uplift of the east Australian Mesozoics. The last portion to disappear was the Coral Sea portion, and the thrusts in Northern Australia connected with the deeps and affecting the earth movements of the present day in north Queensland are Tertiary and Recent. The Coral Sea subsidence probably commenced in the late Cretaceous and is continuing even at present with attendant elevatory movement under the Gulf of Carpentaria. That subject I am dealing with in another paper.

The late Tertiary subsidence of New Caledonia separated from it the Loyalties and other islands of the group and developed the beautiful east coast harbours already referred to. The depression west of New Caledonia is the reaction caused by the early Tertiary upheaval and overthrusts from the east.

APPENDIX.

A Note on the Petrology of a Small Collection of Schists from New Caledonia.

By Germaine A. Joplin, B.Sc., Ph.D.

Thirty specimens have been sectioned and twenty-four of these contain glaucophane. These may be divided into a number of groups which are briefly described hereunder. They were collected from the Diahot Valley and the north-east coast.

1. *Glaucophane Schists.*

(i). *Glaucophane–lawsonite–augite Rocks.*—In the hand-specimen these rocks show a very slight schistosity; they are dark greyish-blue in colour and contain crystals of augite which show a bronzy lustre. Under the microscope two of the specimens show a relict ophitic fabric and two contain large (5 mm.) crystals of augite which suggests a coarse-grained intrusive rock. The augite is frequently threaded with needles and long prisms of glaucophane and the original felspar laths are pseudomorphed by small tabular crystals of lawsonite. One rock contains a good deal of calcite, and albite may be present. Iron-ores and sphene are accessory, and glaucophane shows alteration to chlorite.

(ii). *Glaucophane–epidote Schists.*—These may be subdivided into muscovite-bearing and muscovite-free types. Muscovite is usually accompanied by quartz. In the hand-specimen these rocks are markedly schistose and vary from pale bluish-grey to mottled-green and bluish-grey. The density is fairly high. Under the microscope the dark dense bluish type is found to be very rich in glaucophane and chlorite, and the greenish rocks richer in epidote. Epidote or clinozoisite occurs as granular aggregates between glaucophane crystals or long prisms 1 mm. in length. They are often parallel to the schistosity. Quartz is often abundant and usually occurs in granular aggregates. One rock of this type consists almost entirely of ink-blue glaucophane, and epidote is present only in minute interstitial granules. Sphene is usually abundant in these rocks and may be more plentiful than epidote. In the muscovite-bearing type the mica may often be detected in the hand-specimen.

These schists are often plicated. They show a good deal of variation with respect to the relative amounts of the minerals present. In some cases epidote or clinozoisite is abundant, with muscovite and quartz subordinate, and the rocks appear to grade into the muscovite-free group. On the other hand, epidote and sphene may be present only as a trace and the rocks grade into the glaucophane–muscovite–quartz assemblages described below.

(iii). *Glaucophane–garnet Schists.*—These may also be subdivided into muscovite-bearing and muscovite-free types, and the former grade into the glaucophane–quartz schists which contain very little glaucophane and garnet. The muscovite-free type is represented by a single example which contains clinozoisite as well as garnet and indicates a grade of metamorphism intermediate between that characterized by epidote and that by garnet. This schist also contains a good deal of calcite and chlorite and in the hand-specimen glaucophane-rich and chlorite-rich bands may be discerned.

The muscovite-bearing glaucophane-garnet schists are well represented in the collection examined. Some are extraordinarily rich in glaucophane and the hand-specimen is a dense bluish-grey rock studded with reddish-brown garnets. The types less rich in glaucophane are lighter in colour and more distinctly schistose. Muscovite is sometimes developed in large plates more than 1 cm. across. Under the microscope the garnets are idioblastic and are often in groups. Incipient alteration to chlorite is frequent. When mica is not abundant it often forms radiating masses between glaucophane crystals, but may occur also in large sheets. Clinozoisite is present in some of these rocks.

(iv). *Glaucophane–muscovite–sphene Schist.*—One example of this type is recorded. Except for the absence of garnet and the presence of sphene, it is identical with some of the glaucophane–garnet–muscovite schists. It would appear that the abundant titania inhibited the formation of garnet and that lime entered the sphene molecule, though it is difficult to say why the spessartite molecule should not be formed. Possibly the rock had a deficiency of iron and magnesia and neither of these oxides remained when soda had been satisfied after the formation of glaucophane.

(v). *Glaucophane–muscovite–quartz Schists.*—These rocks are characteristically rich in quartz and poor in glaucophane. Muscovite is fairly abundant and as a rule the glaucophane crystals are larger than in the other schists. In the hand-specimen they are light-coloured quartz-mica schists, often containing large prisms of blue glaucophane which measure 1·5 cm. Several of the rocks show strong plication, and small quantities of garnet and sphene indicate affinities to the above assemblages.

2. *Chlorite–albite–epidote–garnet Schist.*

This rock is somewhat banded with chlorite–epidote layers alternating with albite–epidote–garnet layers. The epidote occurs in long prisms and a slight schistosity is apparent. In the hand-specimen large crystals of pyrites and quartz indicate mineralization.

3. *Chlorite Schists.*

These are soft green schistose rocks consisting almost entirely of chlorite. A little sphene and epidote are sometimes present.

4. *Sheared Hornblende–gabbro.*

The rock is coarse-grained (6 mm.) and consisted originally of brown hornblende and basic plagioclase. Shearing has caused shattering of both minerals and partial saussuritization of the felspar. Chlorite is developed as a secondary mineral.

5. *Garnet Schist.*

This rock has not been sectioned, but in the hand-specimen it is seen to be thickly studded with red, idioblastic garnets which measure about 5 mm. These are set in a groundmass of pale green mica and a little quartz is present.

6. *Chloritoid Schist.*

In the hand-specimen the rock shows a marked schistosity, and black crystals of chloritoid measuring up to 1·25 cm. are embedded in muscovite which is slightly stained by iron-oxides.

Under the microscope the chloritoid shows the characteristic bluish-green colour and the rock is seen to consist almost entirely of chloritoid and muscovite with accessory iron-ores and zircon.

7. *Quartz Schist.*

These consist mostly of quartz and muscovite. Pyrites indicates mineralization.

8. *Actinolite Schist.*

This rock consists of a felted mass of pale green actinolite needles which measure up to 5 mm.

PETROGENESIS.

The writer has no knowledge of the field relations of these various types of schist, and any suggestion made regarding their origin is entirely speculative.

Dr. Jensen considers that the glaucophane-schists are the metamorphosed equivalents of the Mesozoic "andesite series". This series includes a number of types ranging from basalts and dolerites to rhyolites. Some of the earlier writers have designated some of the lavas by the rather indefinite terms melaphyre and ophite, but the present writer has not been able to examine any specimens from this series.

The ophitic fabric of the glaucophane–lawsonite rocks would suggest that at least some of the schists were derived from dolerites, but most of the rocks are too much altered to speculate upon their origin, and detailed field work is desirable.

According to Harker (1932) glaucophane schists are either formed by the metamorphism of alkaline rocks or by the metasomatism of sediments.

It is possible that spilitic lavas may occur in Dr. Jensen's "andesite series", but it is also conceivable that normal basic lavas may have been albitized as the result of deuteric alteration. The old name melaphyre is usually applied to rocks that have suffered late magmatic alteration, and the writer would suggest that under suitable conditions of metamorphism these may give rise to glaucophane schists.

Nevertheless, the lawsonite- and epidote-bearing types indicate that there was an abundance of lime prior to metamorphism, and this suggests a normal calcic rock rather than a deuterically altered or alkaline one. In the case of the lawsonite-bearing rocks with relict ophitic fabric the lawsonite pseudomorphs laths of plagioclase and it is evident that the felspar contained a large percentage of the anorthite molecule. The glaucophane schists rich in lawsonite, clinozoisite or garnet must surely have a composition similar to the albite–epidote rocks, and it has been shown that these latter are not alkaline rocks but that the formation of basic plagioclase has been inhibited by the low temperature conditions.

Washington (1901) has compiled a list of analyses of glaucophane-bearing rocks, and some of these do not indicate a soda percentage above that of normal calcic rocks. It, therefore, seems possible that the formation of glaucophane requires special conditions of metamorphism rather than of composition, though its genesis is possibly facilitated by an abundance of soda. Reference to the petrography will show that the glaucophane rocks occur in several metamorphic grades and for this reason a correlation between the formation of glaucophane and the conditions of metamorphism is very difficult.

It will also be seen that muscovite is a conspicuous mineral in some of the glaucophane rocks. Harker suggests that the glaucophane–muscovite rocks represent tuffs, and this is possible in the present instance, as Dr. Jensen finds tuffs in the "andesite series".

Finally, the quartz–muscovite rocks containing but little glaucophane must surely represent a metasomatized sediment. This is difficult to account for, unless it be assumed that there was adinolization by spilitic lavas or metasomatism of accidental xenoliths by magmatic fluids in calcic lavas.

Those rock types which do not contain glaucophane might be associated with any series of lavas, either alkaline or calcic, and need no further comment.

References.

HARKER, A., 1932.—Metamorphism. A Study of the Transformations of Rock Masses, pp. 134, 291.

WASHINGTON, H. S., 1901.—Study of the Glaucophane Schists. *Amer. J. Sci.*, 11, 35.